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DESIGN FOR DISASSEMBLY TO RECOVER EMBODIED ENERGY

P Crowther
School of Architecture Interior and Industrial Design
Queensland University of Technology
GPO Box 2434, Brisbane, 4001, Australia
fax: 61 7 3864 1528
e-mail: p.crowther@qut.edu.au

ABSTRACT The embodied energy in building materials and components represents a major part of the total energy requirement of any building. When a building is demolished, most of the materials are discarded, and along with them the embodied energy is lost. If buildings were designed for disassembly, rather than demolition, greater proportions of building materials could be salvaged for reuse. In such a scenario, embodied energy would be recovered along with the materials, thereby reducing the total energy requirements of the built environment.

1 Introduction

The construction and operation of buildings requires energy, and the production of that energy, as it is generally carried out, creates major environmental impacts through the generation of CO_2. A reduction in the energy use in buildings will produce a corresponding reduction in environmental damage caused by CO_2. While there has been much research into the possibilities of reducing operational energy consumption, there has been very little investigation into reducing the energy required for the construction of buildings. One of the reasons for this is that it has commonly been accepted that the operational energy of a building over a typical forty year life time is many times greater than the energy required to construct the building. Attention has therefore focused on the area where it was perceived that the greatest energy savings could be made. It now appears however, that operational energy is not the only significant factor. Several recent studies suggest that the initial energy of construction is actually much higher than previously thought. If this is so, we must now consider strategic ways in which to reduce this major energy requirement of construction.

One possible strategy to reduce the energy embodied in construction is to increase the current rates of reuse and recycling of building materials, and the best way to achieve this is to make it easier to do.

Firstly let us consider the magnitude of the energy requirements of the built environment.

2 Operational Energy

The operational energy requirements of a building can be considered as the energy that is used to maintain the environment inside that building. In other words, all energy that is imported into the system to operate lights, lifts and escalators, ventilation systems, heating and cooling systems, water heating and pumping systems. This will include energy from electricity, gas, and the burning of fuels such as oil or coal.

For office buildings it is quite normal for operational energy to be estimated at the design stage and to be measured during the operation of the building. There are numerous codes and targets for operational energy consumption created by government and private organisations. Since operational energy is primarily concerned with maintaining a stable internal environment, these targets of energy use will vary greatly depending on how hostile the exterior environment is. There is therefore, worldwide, a wide range of target values and measured values for energy use in operation. These values for current building practice generally range from as low as 290 MJ/a.m^2 to as high as 1210 MJ/a.m^2 (BOMA 1994, Jaques 1996, Suzuki 1998).

In Australia, where there is a relatively benign climate, the Building Owners and Managers Association (BOMA 1994), have suggested targets for energy consumption in office buildings in the range of from 290 MJ/a.m^2 to 480 MJ/a.m^2. These target figures, and several recent Australian research projects (Donnelly 1991, Treloar 1993, Tucker 1993), suggest that a value of approximately 400 MJ/a.m^2 would be appropriate for the general comparative purposes of this paper.

3 Embodied Energy

The embodied energy of a building can be defined as the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy that is required to manufacture the materials and components of the building. This indirect energy will include all energy required from the raw material extraction, through processing and manufacture, and will also include all energy used in transport during this process and the relevant portions of the energy embodied in the infrastructure of the factories and machinery of manufacturing, construction and transport.

The measuring of embodied energy is currently still not an exacting science. Values for embodied energy of building materials and of complete buildings therefore vary greatly. Until recently it was commonly accepted that the value of embodied energy was relatively low compared to operational energy (Bennetts 1995), and that over a typical forty year life time of an office building the embodied energy would be of the order of 10% of the total energy use. There are however a few recent research projects that suggest that the value for embodied energy is actually much higher than previously calculated. Results from some of these recent studies (Treloar 1993, Tucker 1993), have recorded the embodied energy values for office buildings in Australia to be from 8 000 MJ/m^2 to 9 000MJ/m^2.

These figures suggest that the initial embodied energy of an office building (say 8 000 MJ/m^2) would be significantly higher than 10% of the total energy use over forty years (say 8 000 MJ/m^2 + 40 years x 400 MJ/m^2 = 24 000 MJ/m^2). In fact a figure of 30% to 40% would seem more appropriate.

It is worthwhile looking at this embodied energy value and breaking it down into the direct energy of construction, and the various parts of the indirect energy of the materials and components. A number of recent studies of industrialised building practice (Cole 1996, Oka 1993, Treloar 1993) show that the direct energy used on site to assemble the building is approximately 5% to 13% of the total embodied energy value. Of the remaining energy embodied in the materials and components, approximately 20% to 50% is in the structure of the building, with the remaining 50% to 70% being in the building envelope, the fitout and finishes, and the services. The embodied energy does not however stop with these initial values.

During a typical forty year life of an office building it is reasonable to assume that the building will undergo a number of major and minor refurbishments. Again recent studies (Cole 1996, Howard 1994, Suzuki 1998, Tucker 1993) have shown that the embodied energy in the refurbishment of a building over its life time can be expected to be from 20% to 100% of the initial embodied energy. Even after several refurbishments, when a building has reached the end of its useful life, there will be an energy requirement to demolish it and remove the materials from the site for disposal. This direct energy requirement may be as much as 5% of the initial embodied energy (Suzuki 1998).

4 Total Energy Use

The energy life of a building can therefore be considered to be made up of numerous inputs of operational and embodied energy (Fig. 1). While it is difficult to make meaningful comparisons between the various studies that have been done, there is a general suggestion that embodied energy is an important contribution to the total energy use. If all of the inputs to the system, over a typical life span of forty years, are added together it can be seen that the energy embodied in the building materials can be a highly significant part of the total energy consumption (Fig. 2).

It is important here to note the relatively small portion of the embodied energy that goes into the structure, and the larger proportion that goes into those parts of the building that are subject to periodic replacement during renovation. It is these parts of the building, the facade, the services, and the internal fitout, that have the shortest life span but which contain most of the embodied energy.

It is also worth noting that with the current continuing improvements and reductions in operational energy consumption, the importance of embodied energy is likely to become even greater.

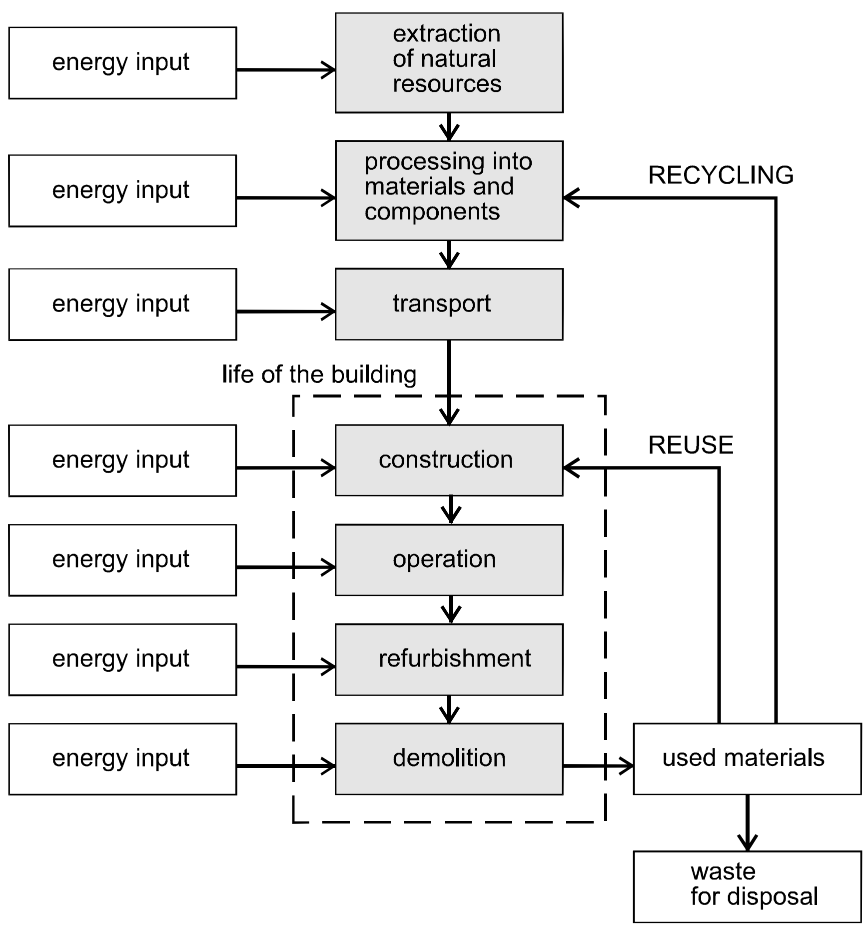

Fig.1 Stages of energy input during the life of a building

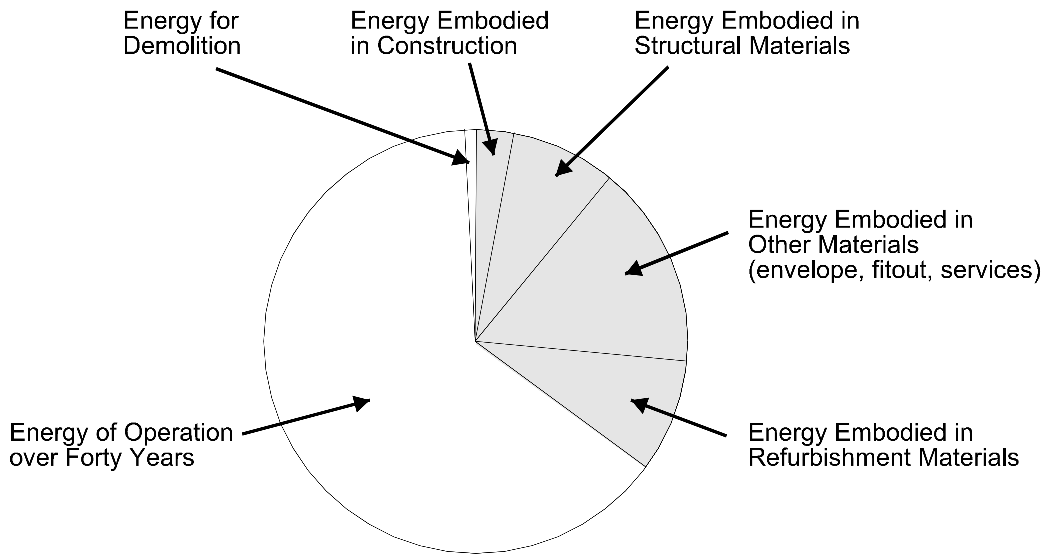

Fig. 2 Total energy use over the forty year life of a typical office building, showing embodied energy as 30% of total energy

5 Disassembly to Reduce Energy Consumption

What then can be done to reduce this large energy burden? There are basically three ways in which we may reduce the total energy consumption of the built environment.

- to reduce energy consumption in operation by designing buildings that maintain an internal environment through the more efficient use of energy and the use of passive energy design
- to reduce embodied energy consumption through the use of low energy content building materials
- to reduce embodied energy consumption through the reuse, recycling and remanufacturing of building materials

Current practice in the construction industry pays little attention to the possibilities of reuse and recycling. In Australia it has been shown that as little as 11% of demolished office building materials and components are reused and only 58% of materials are reprocessed. This leaves 31% to be dumped into landfill, which represents 45% of the building's embodied energy (Tucker 1993). One of the reasons for these alarmingly small rates of reuse is the difficulty of easily separating materials and components that have been permanently fixed into a building. An obvious solution is to design the building to allow for easy future disassembly of materials and component.

If a building were designed for disassembly it can be seen that a major portion of the total energy use of the building could be recovered in the form of materials and components that may be reused, recycled or relocated.

6 Lessons in Disassembly

There are numerous historic examples of buildings that have been designed for disassembly, from the tents of primitive nomads, through the portable colonial cottages and the Crystal

Palace of the nineteenth century, to the visionary work of designers like Buckminster Fuller, Archigram and the Metabolism group. Australia in particular has a strong history of portable and temporary buildings. In fact the first house in the colonial settlement of Brisbane was a prefabricated timber cottage brought from Sydney, though probably originally from Britain. This cottage was originally assembled at Redcliffe in 1824, but the following year was disassembled and relocated to a site in Brisbane (Steele 1975).

A survey of such historic and contemporary buildings reveals common trends in technological practice, and suggests guidelines for designing for disassembly (Crowther 1999). These guidelines cover issues such as:

- the use of mechanical connection rather than chemical ones
- separating structure, enclosure and services
- making components to a size suitable for handling during disassembly
- standardisation and compatibility with other systems
- providing permanent identification of materials, components and procedures
- using common building practice and user participation
- providing access for the disassembly process
- allowing for concurrent or parallel disassembly of components

Some of these issues may seem obvious and indeed many of them have been suggested before as ways to improve materials reuse. In the nineteen twenties, Buckminster Fuller suggested that industries should not sell materials, components and buildings, but rather rent them out and retrieve them for recycling. He also proposed that all architects should know how much their buildings weigh, and that they should achieve ‘maximum gain of advantage from minimal energy input’ (McHale 1962).

Despite this complex history of knowledge, the construction industry has not embraced the concept of designing for disassembly. Buildings are still generally built in the belief that they are permanent even though their expected life span is measured in just a few decades while the materials they are built from may have useful life spans of many centuries.

7 Conclusions

Following a strategy of designing for disassembly may require an initial extra input of direct energy in the construction phase of a building. The physical act of disassembly will certainly require more energy than the more common act of demolition. Even if disassembly requires as much energy as the initial construction of the building it will still represent just a few percent of the total energy use (see Fig. 2). By comparison, the potential recovery of embodied energy in the materials and components salvaged for reuse, could be as high as one third of the total energy use. The potential energy saving could be many times the effort required to realise it.

It is hoped that further research, comparing a design for disassembly strategy with a traditional design for demolition strategy, will confirm these expected energy savings.

It should also be noted that while this paper considers only the energy requirements of buildings and the associated CO_2 production, there are many other benefits in increasing the current rate of reuse and recycling. These include:

- a reduction in the depletion of natural resources
- a reduction in species and habitat loss
- a reduction in waste generation and pollution
- an improvement in human health and social conditions

Clearly the potential of a design for disassembly strategy is worth investigating.

8 References

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